Available online at www.sciencedirect.com

SciVerse ScienceDirect

Procedia Earth and Planetary Science 5 (2012) 354 – 357

Procedia Earth and Planetary Science

2012 International Conference on Structural Computation and Geotechnical Mechanics

# Experimental study on shear fracture of rock with cylindrical specimens

Zhi Wang[a], Wenwen Liu, Yunhai Du, a*

*Department of Engineering Mechanics, Zhengzhou University, Zhengzhou, Henan, 450001, China*

**Abstract**

Shear fracture properties of rock are of importance for structure design and safety assessment in rock engineering. Shear-box test is adopted to determine the Mode II fracture toughness $K_{IIC}$ of sandstone with cylindrical specimens. The experiment and calculation results show that both the tensile and shear stresses exist at the crack tip and the ratio of maximum shear stress to maximum tensile stress, $\tau_{max}/\sigma_{max}$, is about 2~9. The Mode II fracture toughness is about 2~4 times to the Mode I fracture toughness, i.e. $K_{IIC}/K_{IC}$=2~4. Compared with cube specimen, cylindrical specimen has the advantage of convenience sampling, which can guarantee the accuracy of the specimen in situ



*Keywords:* Mode II fracture; fracture toughness; compression-shear; cylindrical specimens; stress intensity factor; rock

## 1. Introduction

In-plane shear (Mode Ⅱ) fracture of rock has attracted more and more interest of researchers in mining, geological and rock engineering. A lot of test methods have been proposed to study Mode Ⅱ fracture of rock, such as four-point bending test [1,2], punch-through shear test [3,4] in which all specimens are subjected to pure in-plane shear (Mode Ⅱ) loading without any tensile or compressive loading. In this case, the new initiated crack propagated at an angle deviating from its original crack plane. The fracture was not true shear (Mode Ⅱ) fracture. In order to realize the true Mode Ⅱ fracture of rock, a compressive loading must be applied to the original crack plane in order to restrain the tensile stress at the crack tip [5, 6]. The Mode II fracture toughness, $K_{IIC}$, of rock was obtained by shear-box test and $K_{IIC}$ was about 2-4 times to the Mode I fracture toughness, $K_{IC}$. However, a cube specimen of rock was hard to process and

* Corresponding author: Zhi Wang. Tel.: +86-371-67783367

*E-mail address*: zhiwang2009@hotmail.com; zhiwang4960_cn@126.com.

 doi:10.1016/j.proeps.2012.01.059

not conducive to in-situ sampling.

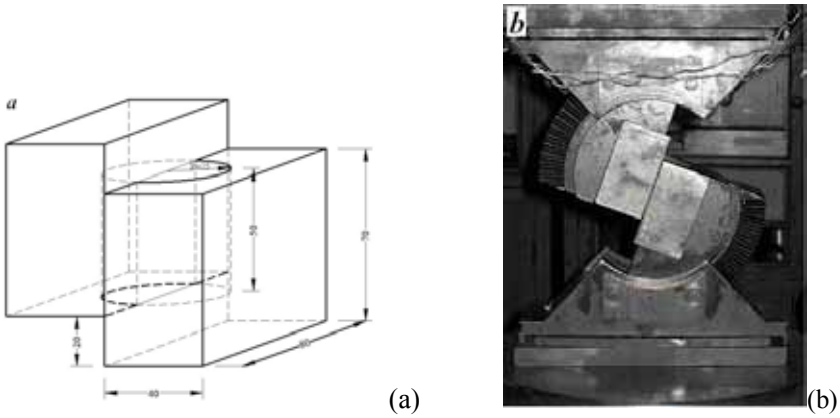
In this study, a cylindrical compression-shear clamp was processed to achieve shear box test. Fracture properties would be studied and Mode II fracture toughness of rock would be tested. The test results would be compared with the results of cube specimens' shear-box test.

## 2. Experiment

Mechanical properties of sandstone produced in Kunming of China are listed in Table 1, including tensile strength $\sigma_t$, cohesion $C$, internal friction angle $\phi$, elastic modulus $E$ and Mode I fracture toughness $K_{IC}$, which are obtained by ISRM (the International Society for Rock Mechanics) standard testing methods. The diameter $D$ and height $W$ of the cylindrical specimen were 50mm. And the single notch width $t$ was 1mm, as shown in Fig.1. Since too large or too low inclination angle $\alpha$ can result in small compressive stresses or local crush. The suggested inclination angle $\alpha$ is 70°. The notch length $a$ were changed from 25mm to 35mm. The average value of the peak load PM would be obtained by 2-3 specimens repeated in the same conditions. Fig.1 (b) shows the loading set-up of shear-box tests. Specimen was tested by an Instron1346 testing machine. The loading rate was 0.05m/s under displacement control.

Table 1. An example of a table

| Mechanical properties parameters | Value |
|---|---|
| Tensile strength/MPa | 2.24 |
| Cohesion/MPa | 14.03 |
| Internal friction angle/° | 35.12 |
| Elastic modulus/GPa | 10.67 |
| Mode I fracture toughness/MPa · $m^{-1/2}$ | 0.549 |




(a) (b)

Fig. 1. (a) Compression-shear specimen and clamp; (b) Loading set-up

## 3. Results and discussion

It can be seen from Fig.2 that the specimens with different notch length obey the same rules. That is, the crack appeared from the crack tip when the load value reach 70%~80% of the peak load and

propagated alone the original crack plane and the initiation angle $\theta$ was about 0 °. Until the load reaches the peak value, the crack propagates rapidly and the Mode II fracture obtain. The fracture surface is approximately flat which is agreeable with the results of the cube specimens (Fig.2 (d)).

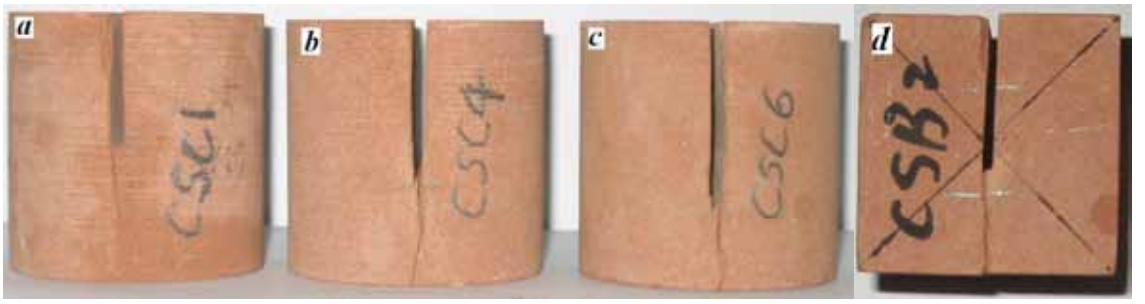



Fig. 2. Fracture trajectory: (a) $a$=25mm; (b) $a$=30mm; (c) $a$=35mm; (d) cube specimen;

There is no formula for calculating stress intensity factor in crack tip $K_{II}$ for cylindrical specimens in compression-shear box test. However, $K_{II}$ can be calculated by displacement method. When distance between the node and the crack tip is far less than the crack length, i.e. $r$ <<$a$, $K_{II}$ can be obtained by linear regression. Under normal circumstances, $K_{II}$ has the following form:

$$K_{II} = FQ_{em}(\pi a)^{1/2}/D/W \quad (1)$$

$$Q_{em} = P(\sin\alpha - \tan\phi\cos\alpha) \quad (2)$$

Where $F$ is shape factor and it can be obtained by finite element method.

The Numerical results also show that the maximum tensile stress $\sigma_{max}$ and the maximum shear stress $\tau_{max}$ exist at the notch tip and the ratio $\tau_{max}/\sigma_{max}$ is about 2-9. The tensile stress can be inhibited effectively under compression-shear loading for the cylindrical specimen. For brittle rock, $\tau_{max}$ can easily reach its limited value before $\sigma_{max}$ and results in the shear (Mode Ⅱ) fracture. Test results of Mode II fracture toughness $K_{IIC}$ can be seen from Fig.3. The ratio $K_{IIC}/K_{IC}$ is about 2-4 which agree well with the results of the cube one.

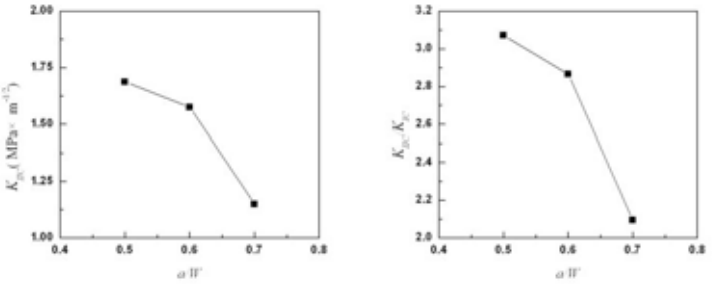



Fig. 3. (a) $K_{IIC}$; (b) $K_{IIC}/K_{IC}$.

## 4. Conclusion

Cylindrical specimen shear-box test have a facilitation in situ sampling, processing, etc., and the precision of process can be controlled easily. In addition, the expansion of the cylindrical specimen can

be limited and the stress distribution in crack plane is more uniform which leads to a slipping along the crack plane. True Mode II fracture can occur in little load. Therefore, Mode II fracture toughness and fracture performance test of rock using cylindrical specimens has good applicability.

## References

[1] Huang J, Wang S. An experimental investigation concerning the comprehensive fracture toughness of some brittle rocks. *Int J Rock Mech Min Sci & Geomech Abstr*, 1985, 22(2): 99−104.

[2] Schlangen E, Mier J G M. Crack propagation in sandstone: Combined experimental and numerical approach. *Rock Mech. & Rock Eng*, 1995, 28(2): 93−110.

[3] Petit J P. Normal stress dependent rupture morphology in direct shear test on sandstone with applications to some natural fault surface features. *Int J Rock Mech Min Sci & Geomech Abstr*, 1988, 25(6): 411−419.

[4] Watkins J. Fracture toughness test for soil-cement samples in mode II. *Int J Fract*, 1983, 23: 135−138.

[5] Rao Q H. Pure shear fracture of brittle rock-a theoretical and laboratory study. Lulea: Division of Rock Mechanics, Lulea University of Technology, 1999: 99−103.

[6] Rao Q H, Sun Z Q, Stephansson O. Shear fracture (Mode II) of brittle rock. *International Journal of Rock Mechanics and Mining Sciences*, 2003, 40(3): 355−375.